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EVALUATION OF SEDIMENTATION AND FILTRATION FOR MICROORGANISM REMOVAL

by

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16. ABSTRACT

Removals of bacteria and Giardia cysts in a pilot plant sedimentation basin were evaluated and compared with turbidity removal. Removal was studied during normal operating conditions, during initial period of filter operation after backwashing, and during times of turbidity breakthrough.

It was concluded that continuous flow sedimentation basins can remove a substantial fraction (perhaps up to 90 percent) of bacteria or cysts in the applied water. Microorganism reduction may be similar to turbidity reduction on a percentage basis.

The tendency of filters to produce water with somewhat elevated trubidity upon restart after backwashing is accompanied by a tendency to pass higher concentrations of cysts and bacteria at the same time. Pilot plant data showed that the probability of attaining high numbers of bacteria or Giardia cysts in filtered water was greater when filtered water turbidities ranged from 0.21 to 1.4 ntu in contrast with data with filtered water trubidities not exceeding 0.20 ntu.

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EVALUATION OF SEDIMENTATION AND FILTRATION FOR MICROORGANISM REMOVAL

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INTRODUCTION

Use of multiple barriers in water supply management and water treatment is considered good public health practice. Barriers intended to prevent the passage of pathogens into finished drinking water may perform at greater or lesser levels of efficacy, depending on circumstances. The intention is that use of multiple barriers will result in drinking water free of pathogens in spite of occasional fluctations in the efficacy of a single barrier. In this paper, some factors influencing the removal of bacteria and Giardia cysts by clarification (sedimentation and filtration) are explored.

Conventional water treatment by filtration is considered to consist of coagulation, flocculation, sedimentation, and filtration. The first two treatment steps condition particles in the water to enhance their removal by sedimentation and filtration. When turbid waters are treated, sedimentation can remove the majority of the particulate matter so that the filter can produce a low turbidity, polished effluent while attaining reasonably long runs.

In this research, removals of bacteria and Giardia cysts in a pilot plant sedimentation basin were evaluated and compared to removal of turbidity. Bacteria and cyst removal by filtration were studied during normal operating conditions as well as during the initial period of filter operation after backwashing and during times of turbidity breakthrough. Because turbidity is one of the most conveniently measured indicators of particulate content in water, data were reviewed to learn if relationships exist between filtered water turbidity and bacteria or cysts in filtered water.

BACKGROUND

Evaluating the capability of water clarification processes to remove microorganisms has been a concern of water treatment engineers for many years. Results reviewed in this paper are from studies in which disinfection, if practiced, was located at a point where it would have no impact on the microbiological data presented.

Sedimentation

Pilot plant and full scale results on microorganism removal by sedimentation without any disinfection effects are less abundant than jar test data, but some results are available. Removal of plate count

bacteria was studied in pilot plants (1) at Pittsburgh, Pennsylvania in 1898 by Hazen. Two coagulation-filtration pilot plants, with flows of about 190 gpm and 240 gpm, were operated at filtration rates of approximately 2 gpm/sf. Detention times for sedimentation were short, on the order of 35 to 40 minutes. Under these operating conditions, at a variety of alum doses, bacteria removal by sedimentation ranged from 24 to 55%, based on monthly averages. Considerable variation was observed in daily results, and sometimes plate count bacteria concentrations in settled water were as high as those in the raw water.

Three decades later Streeter (2,3) evaluated bacteria removal at full scale plants, and reported results ranging from 46 to 83 percent. The better removals reported by Streeter may reflect use of settling basins with theoretical detention times of several hours, in contrast to theoretical detention times of less than one hour in the proprietary coagulation-filtration plants evaluated by Hazen at Pittsburgh.

More recently, Cummins and Nash reported that total coliform removal by coagulation and sedimentation at a water treatment plant was 42 percent when these processes had been preceded by 48 hours of sedimentation during raw water storage. Haas et al (5) reported that total coliform removals by coagulation and sedimentation ranged from 60 to 99.5 percent when aluminum or iron salts were used under optimum conditions in jar tests

Data on cyst removal by sedimentation are available from a few sources. Spector et. al. reported that removal of Endamoeba histolytica cysts ranged from 27 to 78 percent in batch tests in which alum was the coagulant (6). Arozarena (7) obtained G. muris cyst removals ranging from 58 to 99 percent in jar tests with alum coagulation.

Conventional Treatment

Removal of plate count bacteria by coagulation, sedimentation, and filtration in pilot plant studies at Pittsburgh ranged from 85 to 99 percent (1). Streeter (2,3) reported that Escherichia coli removals ranged from 90 percent to over 99.9 percent, depending on whether the source water was from the Great Lakes or the Ohio River, and on the concentration of bacteria in the raw water. Conventional treatment efficiencies were greater when raw water bacteria counts were higher, and when source waters were more turbid (Ohio River vs. Great Lakes). Recently, O'Connor et. al. (8) reported that during winter removal of bacterial cells (measured by acridine orange direct count) ranged from 31 percent to 95 percent at seven conventional treatment plants. Most plants were attaining removals in the 80 to 90 percent range. At the same plants during the summer, removals ranged from 90 percent to 99.987 percent, with most plants removing 97 percent or more of the bacterial cells in the raw water.

The performance reported by O'Connor et. al. was not as effective as that reported by Streeter. Two likely causes for this would be the different analytical methods used and presentation of average vs. individual results. The acridine orange direct count method reports both live and inactivated bacterial cells whereas culture techniques enumerate only organisms that can multiply in the medium used for enumeration. In addition, the possibility exists that the staining and direct counting technique could result in reporting of false positives if other biological matter, similar to bacterial cells under microscopic

examination, were present in the sample examined. Streeter's data on the capacity of treatment plants to remove bacteria were presented as equations describing average results, in order to smooth out the variation observed in individual data points. This would narrow the range of data presented by Streeter, as opposed to the broader range of data reported as individual samples by O'Connor.

Various investigators have shown that when a granular media filter run is started, filtered water quality frequently is deteriorated for a short while, but it quickly improves. The causes of this initial degradation of the filter effluent quality was explained very well by Amirtharajah and Wetstein (9). Data from a very early investigation of water quality just before and after filter washing were presented in the Pittsburgh report (1). Tabulated data from Pittsburgh were presented graphically (10) by Logsdon and Lippy. The Pittsburgh filter washing data were obtained in work in which disinfection was not practiced and thus should depict filter behavior rather well. Results of 20 runs showed that plate count bacteria concentrations were always higher shortly after initiation of a new run than they had been just before the previous run was terminated. Also in about half of the runs, the concentration of plate count organisms increased after the first sample was collected in the new run.

EXPERIMENTAL INVESTIGATIONS

Pilot Plant

These studies were carried out with the U.S. Environmental Protection Agency's 2 gpm pilot plant in Cincinnati. This plant was described in detail by Sorg and Logsdon (11), and its use for Giardia treatment studies was reported upon recently (12). Processes used were two-stage rapid mix, flocculation, sedimentation, and filtration. Alum was used as the coagulant, and in some runs, a slightly anionic high molecular weight polymer was used to strengthen the floc. Six different filters were used in the work. One bank of three filters contained dual media, anthracite mono media, and sand. Two filters in a second bank of three contained dual media, and the third held granular activated carbon. All filters were 4-1/4 inches in diameter. Table 1 has design information for the filters. Filters were operated at 3 gpm/sf.

The water source for these studies was the Ohio River. Raw water was stored at EPA in a 7000 gallon stainless steel tank until needed. Turbidity of the water ranged from 7 to 25 nephelometric turbidity units (NTU) in the Giardia treatment research, and in one instance a clay-topsoil slurry was added to the water to obtain turbidiy in the 27 to 32 NTU range. In the studies conducted for bacteria removal raw water turbidity ranged from 5 to 25 NTU.

Microbiological Methods

When the Giardia studies (12) were conducted, the raw water was spiked with G. canis or G. muris cysts. The cysts were added in a slug dose in the first two test series and continuously in the last two test series. Applied cyst concentrations were calculated, based upon hemacytometer counts of the concentrated cyst suspension. Settled water and filtered water cyst concentrations were determined by filtering treated water samples through 142 or 293 mm diameter, 5 um pore size polycarbonate filters. Sample collection times ranged from 10 minutes

to several hours. Residue was washed from the filters, concentrated by centrifugation, and counted in a hemacytometer.

When bacteria removal by conventional treatment was evaluated, a laboratory culture of Klebsiella pneumoniae, exhibiting a positive fecal coliform reaction, was used as the bacterial spike for six of the pilot plant experiments. The organism was inoculated onto a tryptic soy agar slant with a slope of approximately 2.5 inches in a 125 by 16 mm screw cap culture tube. The entire agar surface was streaked with the inoculum to develop a continuous growth film. Two such cultures were prepared and incubated for 18 to 24 hours at 35°C. After incubation 1 mL of 0.0003M phosphate buffer was pipetted onto the agar surfaces and the growth was emulsified by gently rubbing the bacterial film with a pipette. The contents of each tube were then pipetted into a 99 mL 0.0003M phosphate buffer dilution blank (13). The two dilution blanks containing the organism were then aseptically added to 1,800 mL of 0.0003M phosphate buffer in a large plastic graduate cylinder containing a magnetic stirring bar. The graduate was then placed in an insulated box and surrounded by ice. The box containing the graduate was placed on a magnetic stirring apparatus to allow for uniform mixing of the culture. The graduate was covered with aluminum foil with an opening for a glass tube to be inserted for the removal of the spike organisms. A lid for the insulated box, containing the appropriate opening, was then put in place to insure proper insulation. The bacterial spike was fed into the raw water inlet line to the pilot plant by means of a peristaltic pump at the rate of 1 mL per minute.

In two of the experiments sewage was used as the microbiological spike. In these experiments 5 gal of raw or primary effluent domestic sewage was placed in 5,000 gal of Ohio River water for three to five days prior to the start up of the pilot plant. The water was continuously mixed by means of a recirculation pump which moved the water from one end of the holding tank to the other.

After pilot plant operation was started an interval of approximately 24 hrs of operation was allowed to elapse, so the pilot plant could reach a state of equilibrium, prior to beginning the microbiological sampling. Grab samples of raw river water, river water containing the bacterial spike, settled water and effluents from the various filters were collected at appropriate time intervals. In addition to these samples filter backwash samples were also collected in three of the experiments. Chlorinated and dechlorinated back wash water was used in two identical dual media filters in these experiments. Microbiological samples collected from the filters which had been backed washed with chlorinated water were dechlorinated immediately upon collection by the addition of a 10% (W/V) sodium thiosulfate solution to each of the sample bottles (1 mL per liter). Samples were also taken for chlorine determinations at the time of the collection of the microbiological samples from the chlorinated back wash filter effluents. The samples were analyzed for free chlorine using the N,N-diethyl-p-phenylenediamine colorimetric method (14).

Samples were analyzed for total coliform bacteria, total heterotrophic bacteria and specifically for Klebsiella, a known pathogen and a member of the total coliform group. The membrane filtration procedure (MF) using m-Endo LES agar was used to determine total coliforms and the pour plate procedure using plate count agar was used to enumerate the heterotrophic population (14). A newly developed medium

(m-Kleb) was used to determine the number of Klebsiella spp. This medium, incorporating the antibiotic carbenicillin and using adonitol as the carbon source, is highly specific for members of the genus Klebsiella (15). Samples were analyzed in triplicate for all three procedures with the exception of initial experiments where several dilutions were used to ascertain the appropriate bacterial titer. Selected bacterial isolates from the m-Kleb medium were speciated for the experiments where the sewage spike was used. Ten percent of the colonies from a given m-Kleb plate chosen from one particular time from each sampling location were picked and isolated for identification. Speciation was performed using the API 20E system (Analytab Products, Plainview, N.J.*).

Other Measurements

Water analysis was also performed for turibidity, pH, and alkalinity. A Hach 2100 A® turbidimeter† was used. Grab samples of raw, settled, and filtered water were analyzed. Sampling frequency was once per hour for raw and settled water. Filtered water was tested each hour, or more frequently when turbidity was rising or immediately after backwash. Alkalinity was determined by titration to the methyl orange endpoint, and pH was measured electrometrically.

Pilot plant flows were measured with municipal water meters. Head loss was indicated by piezometer tubes. Volume of chemical feed solution or cyst suspension in graduated cylinders was recorded periodically. Chemical feed rates, applied cyst concentrations, and filtration rates were calculated from these data.

RESULTS

Sedimentation

Giardia cyst removal by sedimentation is compared to turbidity removal in Figure 1. Removal of heterotrophic plate count organisms is also compared to turbidity removal in Fig. 1. Bacteria removal ranged from 34 percent to 94 percent, while cyst removal ranged from 65 to 93 percent. In general, microorganism removal by sedimentation was found to be similar to the degree of turbidity removal accomplished by sedimentation.

Conventional Treatment

Evaluation of conventional treatment was done by comparing filtered water quality and raw water quality. Filter runs are generally considered to consist of up to three phases, with respect to water quality. Most runs begin with a rapid deterioration of quality, followed by a period of improvement. Often, filter runs have an extended period during which water quality is stable. Finally some filter runs exhibit a period of deterioration of water quality at the end of the run, called turbidity breakthrough. The three phases of filter runs are considered separately in this paper.

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*Mention of commerical products does not constitute endorsement by the U.S. Environmental Protection Agency.
†A product of Hach Chemical Company.

The portion of the filter run producing a stable effluent quality is the portion of the run that plant operators want to maximize. Data are presented in Table 2 to indicate the concentration of organisms in the filter effluent and the percentage of reduction attained by conventional treatment. To show the level of performance that could be attained by conventional treatment, data include samples with filtered water turbidities not exceeding 0.20 NTU. This value was selected because of the smaller size of the data base with turbidities not exceeding 0.10 NTU. Results in Table 2 show that generally some cysts did pass through the conventional treatment process, although removals varied from 97 percent to 99.98 percent when the treatment plant was working well. Klebsiella pneumoniae removals were 5 orders of magnitude or more (above 99.999 percent) when spiked, cultured organisms were used. Klebsiella removals exceeded 99 percent when sewage was added to the raw water and the biological population was allowed to remain for about five days in the low-nutrient condition presented by the river water. In both cases, however, conventional treatment with no disinfection was capable of reducing Klebsiella to near or in some cases below the level of detection (1/100 mL). All 49 of the isolates picked from the m-Kleb medium for the sewage experiments were confirmed to be members of the genus Klebsiella. The concentration of heterotrophic plate count organisms was never as low as 1 per mL, regardless of whether cultered organisms or sewage organisms were added to the raw water.

Turbidity breakthrough conditions were observed during experiments for cyst removal and for bacteria removal. Examples of filter behavior are shown in Figures 2-4. Figure 2 shows filtered water turbidity and Giardia cyst concentrations for portions of two filter runs. Between 10 and 20 hours elapsed time (not shown), turbidity was 0.2 NTU or lower. Later turbidity rose to around 0.3-0.4 NTU, and spiked to 1 NTU. Although the Maximum Contaminant Level (MCL) for turbidity was not exceeded, this should be considered a turbidity breakthrough, if the filter is operated for control of Giardia cysts. After the filter was backwashed, turbidity dropped to 0.09-0.17 NTU, and cyst concentration was 17 cysts/L, in contrast to the 340 and 630 cysts/L measured before the previous run was ended.

Figure 3 shows water quality data for a filter run during a Klebsiella spiking experiment. As turbidity increased from less than 0.2 NTU to 0.6 NTU, Klebsiella and total coliform counts in filtered water increased by two orders of magnitude. This test involved addition of very high numbers of bacteria to the raw water. Another example of turbidity breakthrough is illustrated in Figure 4. During this run with a dual media filter, turbidity and microorganisms counts were low from 23 through 35 hours of operation. The pilot plant was run through a second night of operation, and at hour 46 turbidity and microbiological samples were collected and analyzed. Turbidity had increased from just under 0.10 ntu to 0.25 ntu, and total coliform and Klebsiella concentrations had also increased by factors of 4 or more.

Because of the strong likelihood that larger numbers of microorganisms might pass through a filter just after washing and restart, samples were collected for cyst analysis during the first 30 to 35 minutes after backwashing during seven filter runs when the Giardia treatment studies were carried out. Data indicated cyst concentrations were higher during filter ripening than during times of stable water

quality in four of the seven runs in which backwashing was studied. (An example was shown in Fig. 2).

When the filter ripening phenomenon was studied in the bacteria treatment studies, two dual media filters, located side by side, were used. This was done three times with spiked Klebsiella organisms and once with sewage organisms to verify that results were reproducible. These filters were both operated at approximately 3 gpm/sf. After backwashing, both were started at the same time. Samples from the filter washed with dechlorinated tap water (Fig. 5) revealed a pattern similar to the Pittsburgh (1) data. The bacteria concentration rose rapidly, and then it gradually declined. The rise and decline occurred at about the same time as the rise and decline in turbidity.

When chlorinated backwash water was used, no Klebsiella organisms were detected for the first 10 minutes (Fig. 6). This would be expected because of the rapid rate with which free chlorine inactivates coliform organisms, and it explains why early data, obtained before disinfection was practiced, differ from most of the modern data. Results similar to those shown in Figs. 5 and 6 were obtained in the other filter washing tests.

DISCUSSION

The studies of initial effluent quality after backwashing indicate that the potential for microorganisms to pass a filter is greater at the beginning of a run than later on, when effluent quality is stable. The present findings are consistent not only with results obtained before chlorination was practiced, but also with Cleasby's recent direct filtration results (16) from a study of filtration for small systems. Coliform removal percentages were lower during the first hour of the run than during the remainder of the run in nearly every instance in that investigation.

Clearly, more microorganisms are likely to be present in filter effluent just after a filter is washed. Comparisons of washing with chlorinated vs. dechlorinated water suggest that readily inactivated organisms may not be viable during the first 5 to 15 minutes after a filter run begins, but unless the organisms have lysed or disintegrated, they would still be passing through the filter. Inactivated organisms might serve as a source of nutrients for bacteria in the distribution system. Injured bacteria might pass through just after filter washing, and later reproduce and colonize in the distribution system.

Research results indicate that turbidity breakthough often coincides with larger numbers of microorganisms passing the filter. The increase in microorganisms may be considerably greater than the increase in turbidity. Filtered water total coliform and Klebsiella data from this study have been grouped according to turbidity of the filtered water at the time of sample collection. Because of the effects of chlorinated wash water on bacteria, no total coliform or Klebsiella data for 5 min. to 30 min. after filter washing and start-up were included. Probability plots (Figs. 7 and 9) show the probability of observing less than a given total coliform or cyst concentration for the low turbidity and high turbidity data groups. The data were separated into two groups: 0.20 NTU or lower and 0.21 NTU or higher. Giardia cyst data from the 1984 pilot plant study were put in similar groups, but because of the long sample times involved, the highest turbidity observed during sampling was used to classify the cyst data. For

Giardia cysts, the data clearly separate into different groups according to the turbidity of the filtered water (Fig. 7). An even more dramatic separation was seen for the probability plot using data from spiked Klebsiella pilot plant tests (Fig. 8). Sewage spiking data (Fig. 9) do not show such a degree of separation especially with regard to the higher concentration of total coliforms observed in each turbidity group. Nevertheless, for a filter that always produces water with turbidity ranging from 0.21 to 1.4 NTU (meets the MCL), vs. a filter that always produces water of 0.20 NTU or lower, total coliforn counts in the low turbidity effluent would be no more than 25 percent of the counts in the high turbidity effluent half of the time. Thus even though a direct, proportional relationship does not exist between the concentration of cysts or total coliforms in filtered water and the turbidity of that water, Figures 7 - 9 show that a filtration plant that backwashed its filters at 0.20 or lower NTU and routinely produced water below 0.20 NTU would expect to have fewer coliforms or cysts in filtered water than a plant that allowed effluent turbidity to approach 1 NTU and backwashed at 1.4 NTU or less, in order to avoid violations of the turbidity MCL.

The results of both cyst and bacteria removal studies suggested that microorganism removal percentages by coagulation and sedimentation were similar to turbidity removal percentages. Results from batch sedimentation studies have indicated that much better removals could be obtained, in some cases 99 percent. To help answer the question of whether the data from a 2 gpm sedimentation basin could be representative of full scale results, some data from Streeter (2) were tabulated and appropriate calculations were performed. Figure 10 shows the removal percentages for plate count bacteria vs. turbidity (measured as p.p.m., silica standard). For both turbidity and plate count data, weekly averages were available for the Cincinnati filtration plant for 12 months during 1915 and 1916. At that time, the Cincinnati treatment scheme was plain sedimentation, coagulation-sedimentation, filtration, and then disinfection. The turbidity reduction percentage was that obtained by coagulation-sedimentation, i.e., effluent from the plain sedimentation basin was considered raw water because it had received no chemical treatment. Influent turbidity ranged from 4 to 211 (ppm silica) in Streeter's data.

Results in Fig. 10 are similar to pilot plant results shown in Fig. 1, although a greater spread exists in the full-scale data. All the results support the concept that microorganism removal by coagulation and sedimentation is not likely to exceed 90 percent on a consistent basis in continuous flow basins. Thus in a conventional treatment plant, although the greatest numbers of microorganisms (i.e., over 50 percent) would be removed by sedimentation, effective filtration is essential to obtain really high removal percentages of microorganisms, such as 99 to 99.99 (two to four logs of removal). Thus water must be prepared by coagulation and flocculation not simply for effective sedimentation, but for effective sedimentation and filtration.

CONCLUSIONS

Continuous flow sedimentation basins can remove a substantial fraction (perhaps up to 90 percent) of bacteria or cysts in the applied water. Microorganism reduction may be similar to turbidity reduction on a percentage basis.

The tendency of filters to produce water with somewhat elevated turbidity upon restart after backwashing is accompanied by a tendency to pass higher concentrations of cysts and bacteria at the same time. The passage of bacteria during this phase of filter operation is likely to be masked by chlorination.

Pilot plant data obtained in this study showed that the probability of attaining high numbers of bacteria or Giardia cysts in filtered water was greater when filtered water turbidities ranged from 0.21 to 1.4 ntu in contrast to data with filtered water turbidities not exceeding 0.20 ntu. A recommended operating strategy to minimize passage of microorganisms through a conventional treatment plant would be to produce a filtered water with turbidity below 0.20 ntu, and backwash each filter when it's effluent turbidity rose to 0.20 ntu.

The m-Kleb medium proved to be a highly selective medium with excellent differential characteristics for determining levels of members of the genus Klebsiella in the treatment process waters examined.

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TABLE 1. MEDIA USED IN FILTERS

Media	Depth in.	Depth m	Effective Size mm	Uniformity Coefficient
Dual media				
Anthracite	20	0.51	0.99	1.13
Sand	10	0.25	0.46	1.24
Sand	30	0.76	0.42	1.55
Anthracite	30	0.76	0.92	1.64
12 x 40 GAC*	32	0.81	0.55-0.65	$\leq$1.9

*Filtrasorb F-400, Calgon Corp., Pittsburgh, Pa.

TABLE 2. MICROORGANISM REMOVAL BY CONVENTIONAL TREATMENT

FILTERED WATER TURBIDITY 0.20 NTU OR LOWER

Organism	Raw Water Concentration	Filtered Water Concentration	Percent Removal
Giardia	141/L	<1.3/L	>99.0
Giardia	336/L	3.7/L	98.9
Giardia	128/L	3.4/L	97.3
Giardia	8,600/L	<1.9	>99.978
Giardia	8,600/L	17/L	99.8
Giardia	31,000/L	5.2/L	99.98
Giardia	31,000/L	19/L	99.94
Cultured Klebsiella	3.7×10^5/100 mL	<1/100 mL	>99.9997
Cultured Klebsiella	4.5×10^5/100 mL	2.3/100 mL	99.9995
Cultured Klebsiella	5.5×10^5/100 mL	<1/100 mL	99.9998
HPC	5,930/mL	123/mL	97.9
HPC	7,190/mL	208/mL	97.1
HPC	3,400/mL	49/mL	98.5
Sewage Klebsiella	2,280/100 mL	2/100 mL	99.91
Sewage Klebsiella	2,280/100 mL	<1/100 mL	>99.95
Sewage Klebsiella	99/100 mL	<1/100 mL	>99
Sewage HPC	1,510/mL	43/mL	97.1
Sewage HPC	1,510/mL	14/mL	99.1
Sewage HPC	805/mL	25/mL	96.9

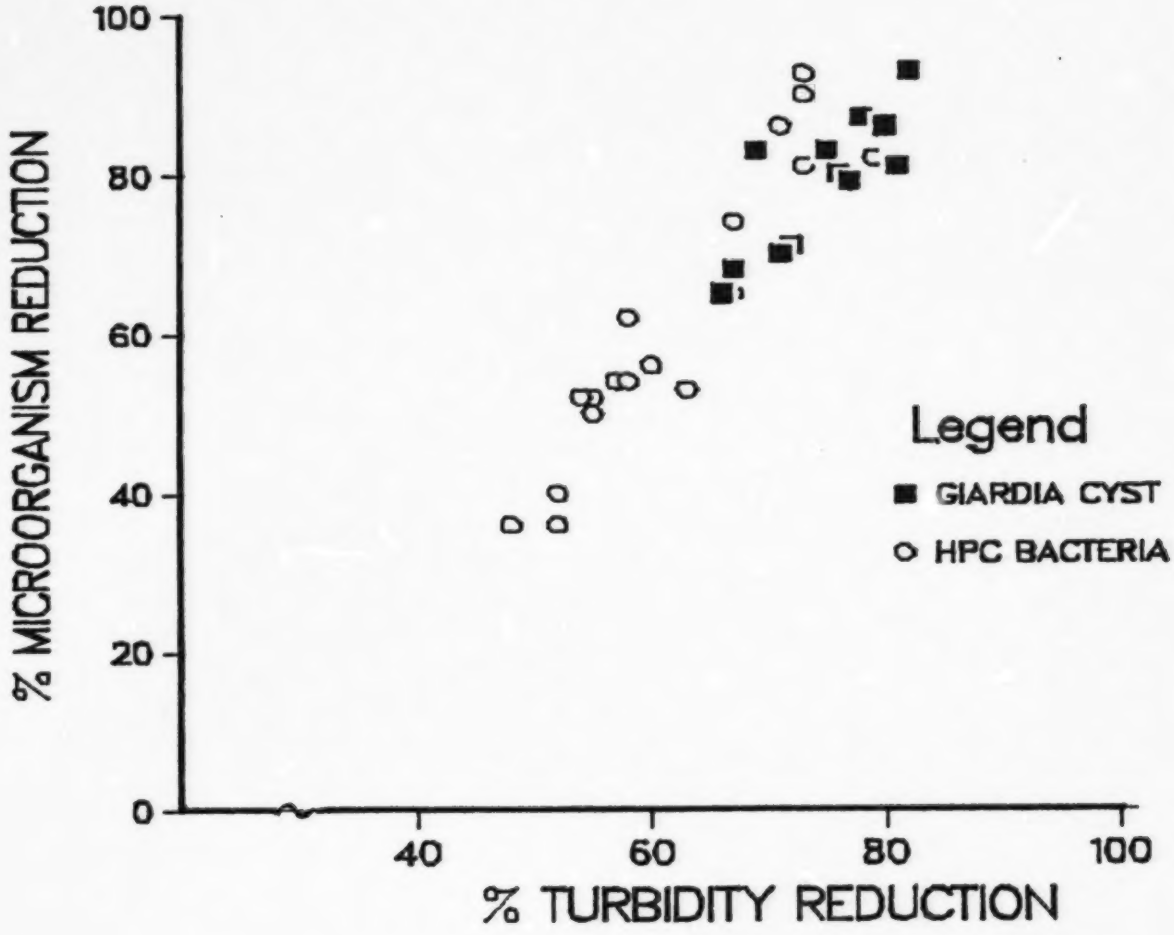

Figure 1. COAGULATION - SEDIMENTATION RESULTS

EPA PILOT PLANT 1984-1985

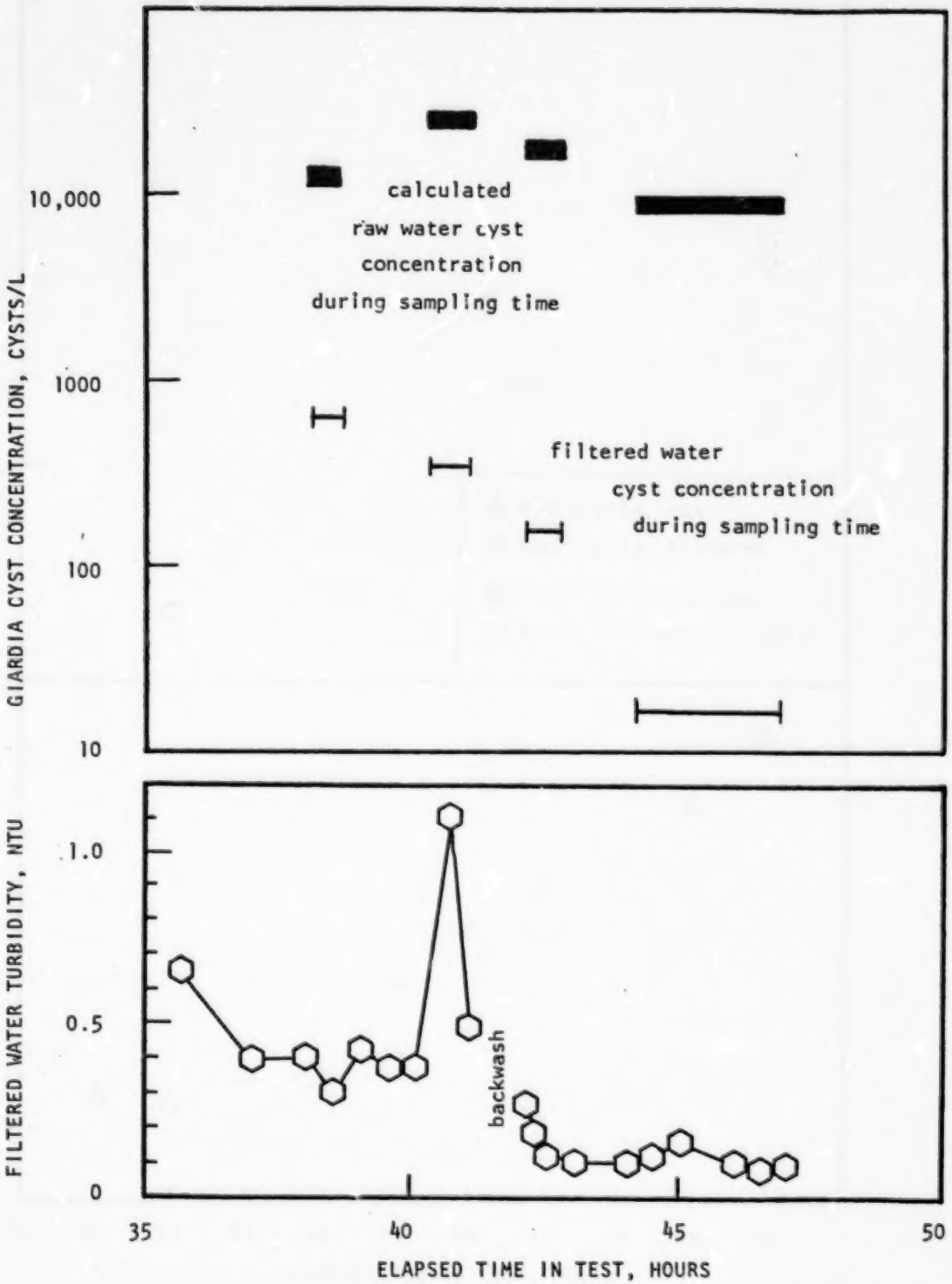

Figure 2. ANTHRACITE MEDIA FILTER DATA 8/12-15/84

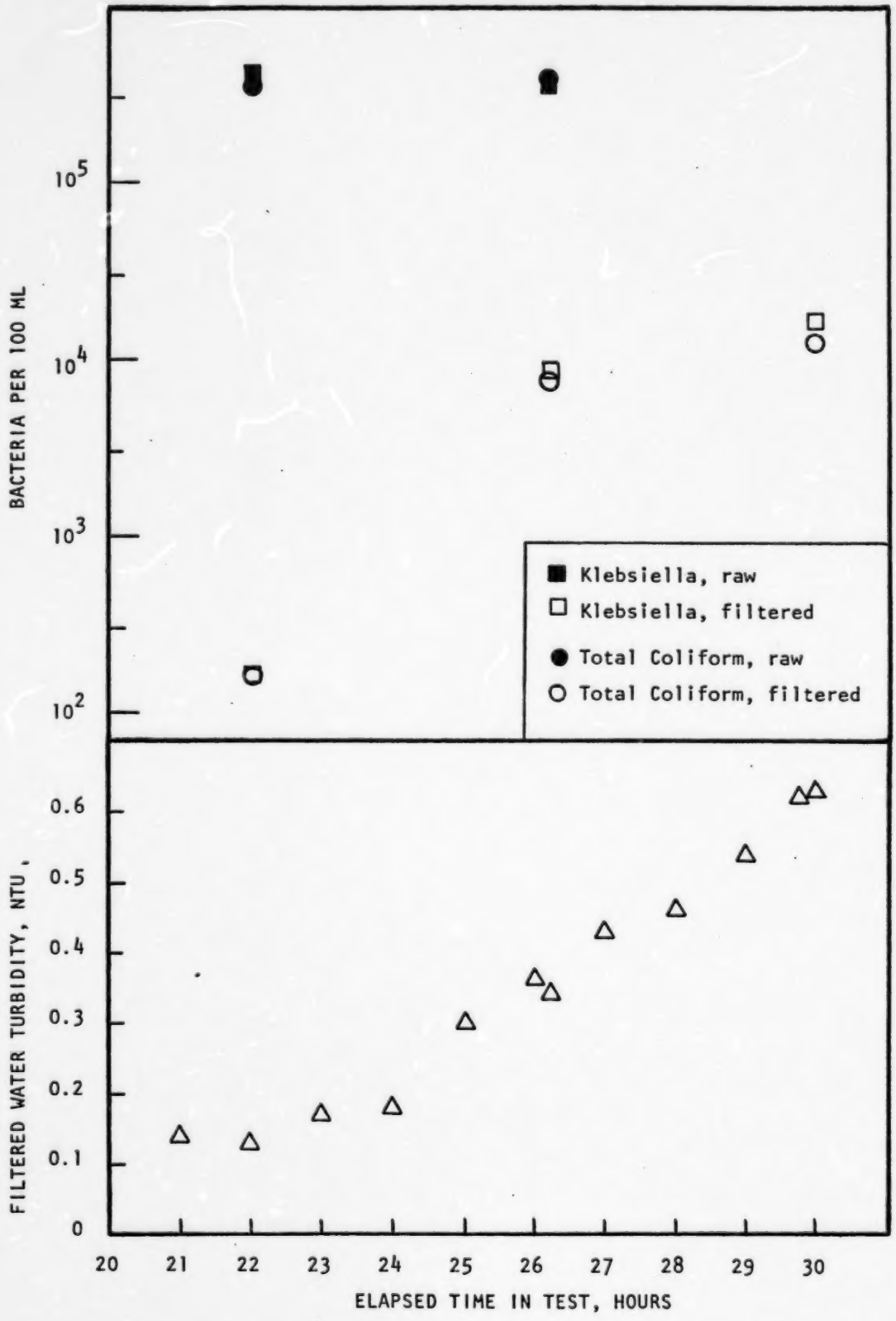

Figure 3. ANTHRACITE MEDIA FILTER DATA: KLEBSIELLA SPIKE 2/25/85

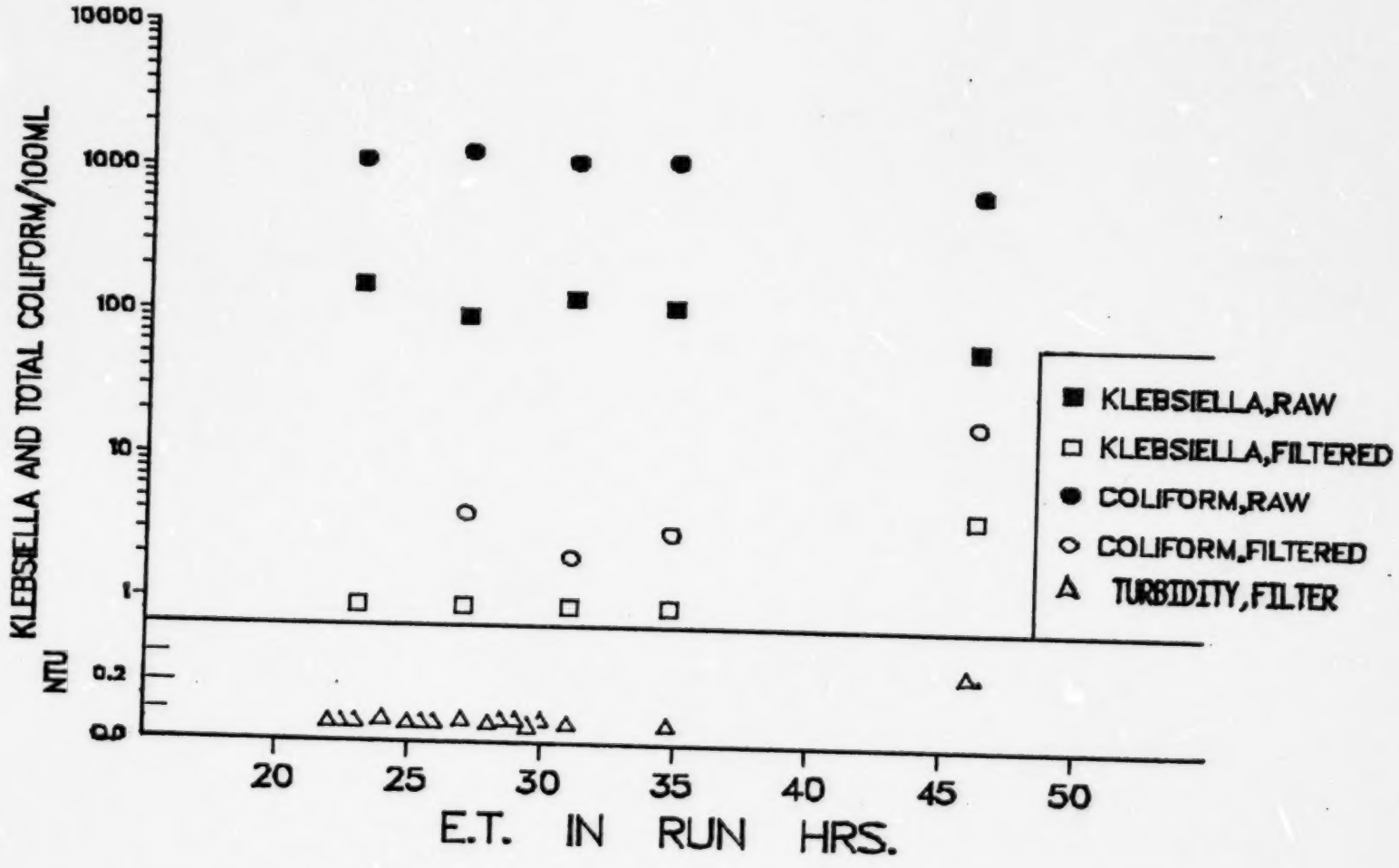

Figure 4

DUAL MEDIA FILTER 4/29/85 SEWAGE SPIKE

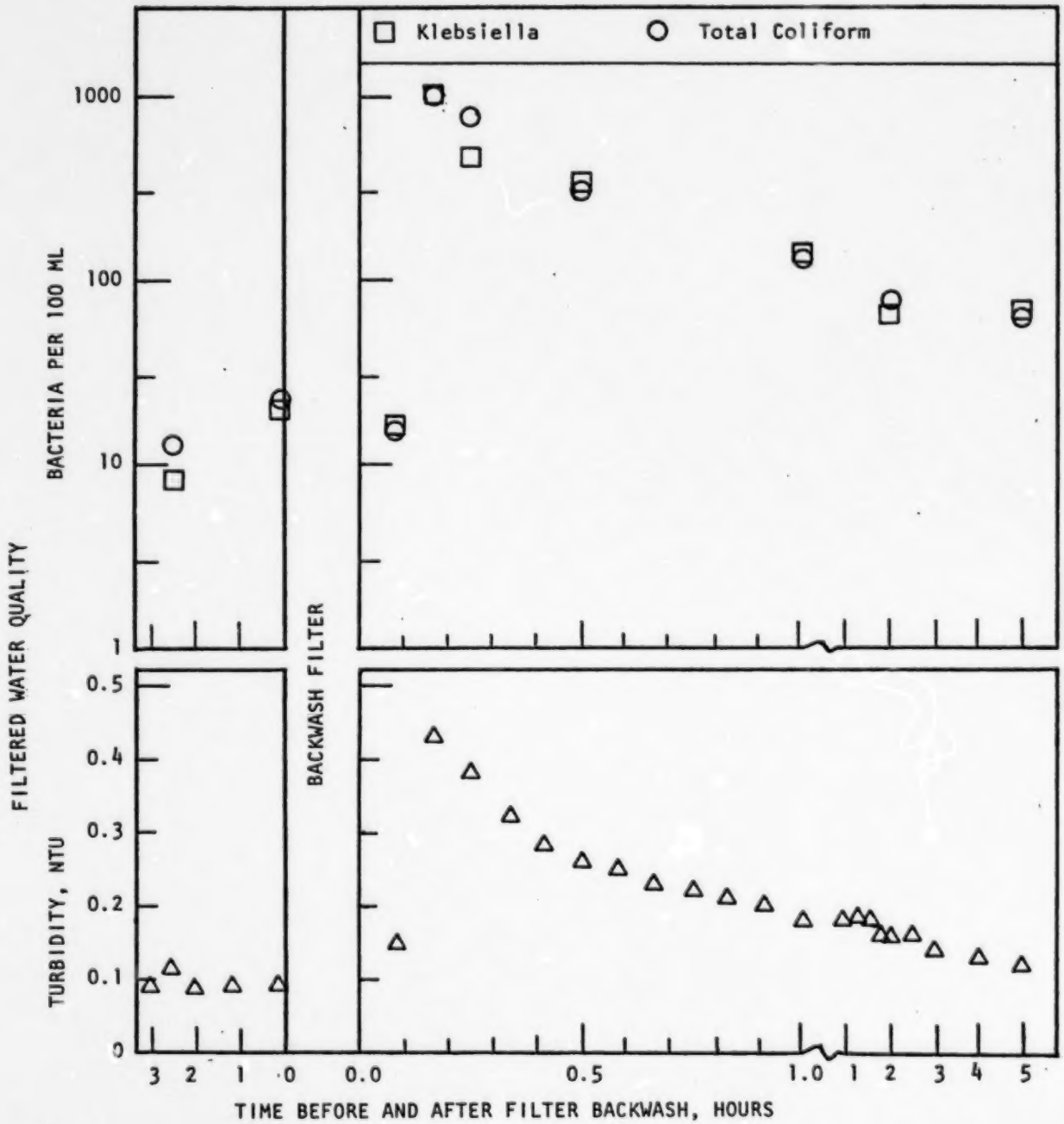

Fig. 5. INFLUENCE OF FILTER WASHING ON WATER QUALITY, DECHLORINATED WATER USED (KLEBSIELLA SPIKE 4/15 - 16)

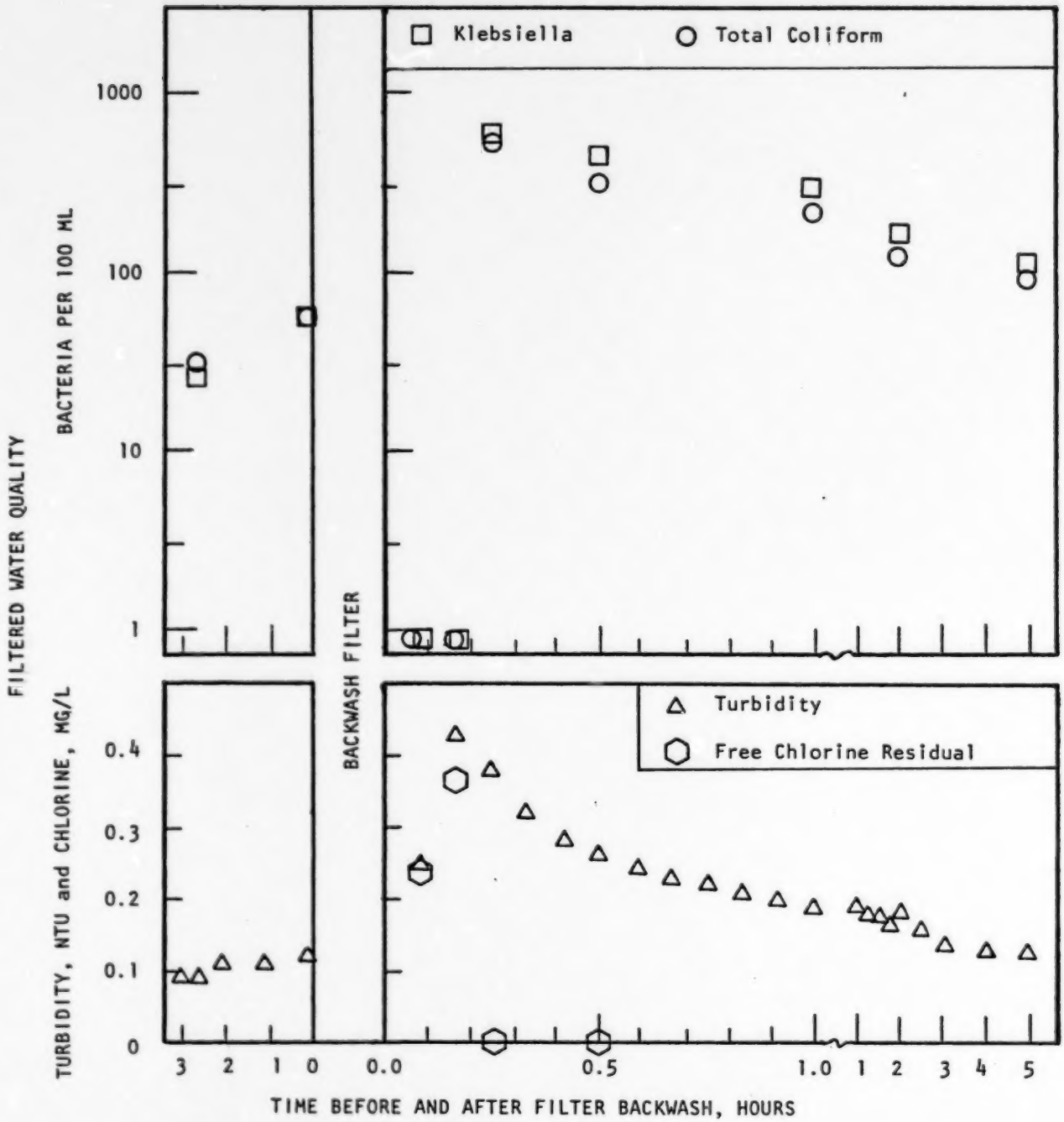

Fig. 6. INFLUENCE OF FILTER WASHING ON WATER QUALITY, CHLORINATED WASH WATER USED (KLEBSIELLA SPIKE 4/15 - 16)

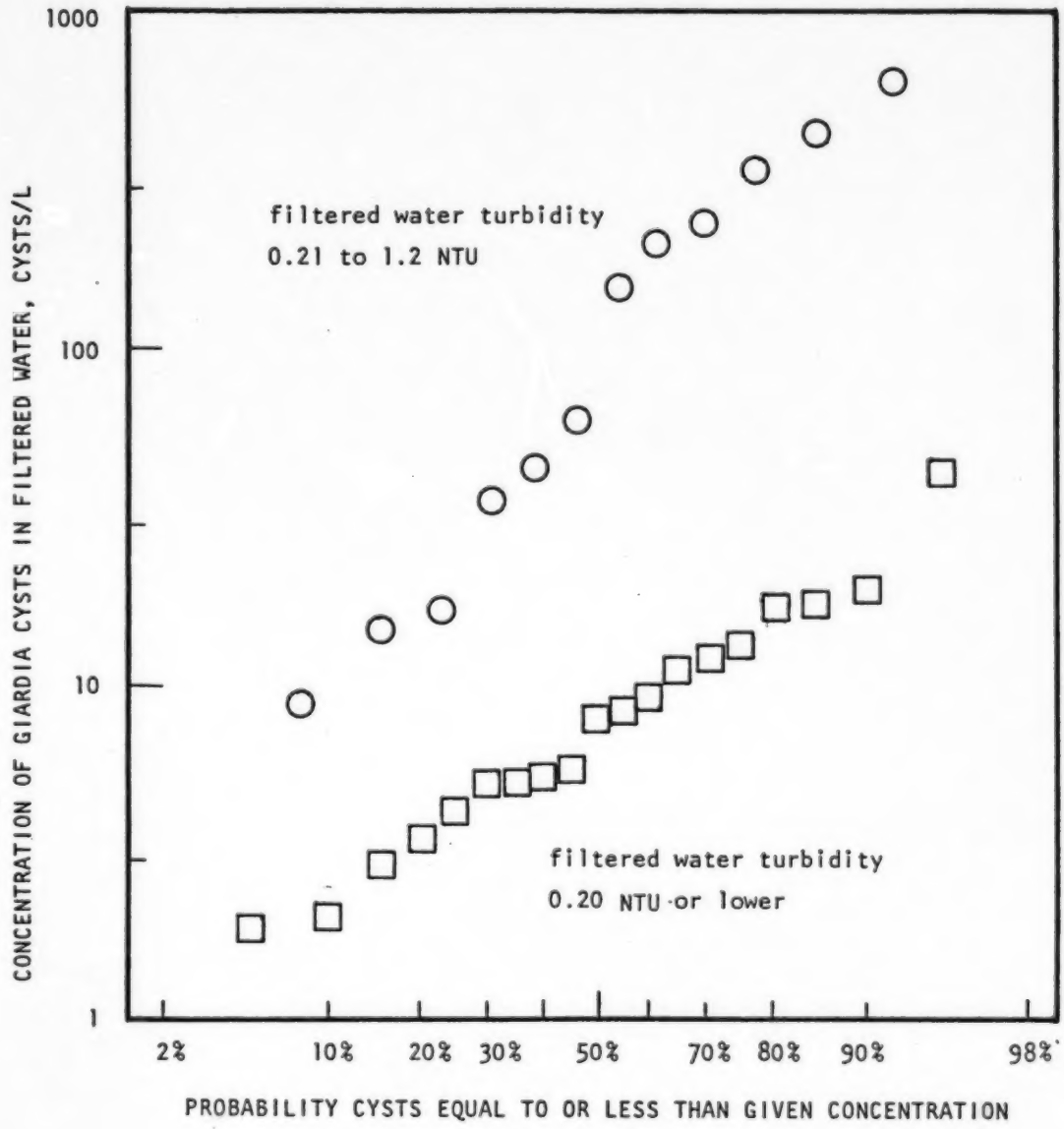

Figure 7. RELATIONSHIP OF TURBIDITY AND GIARDIA CYSTS IN FILTERED WATER

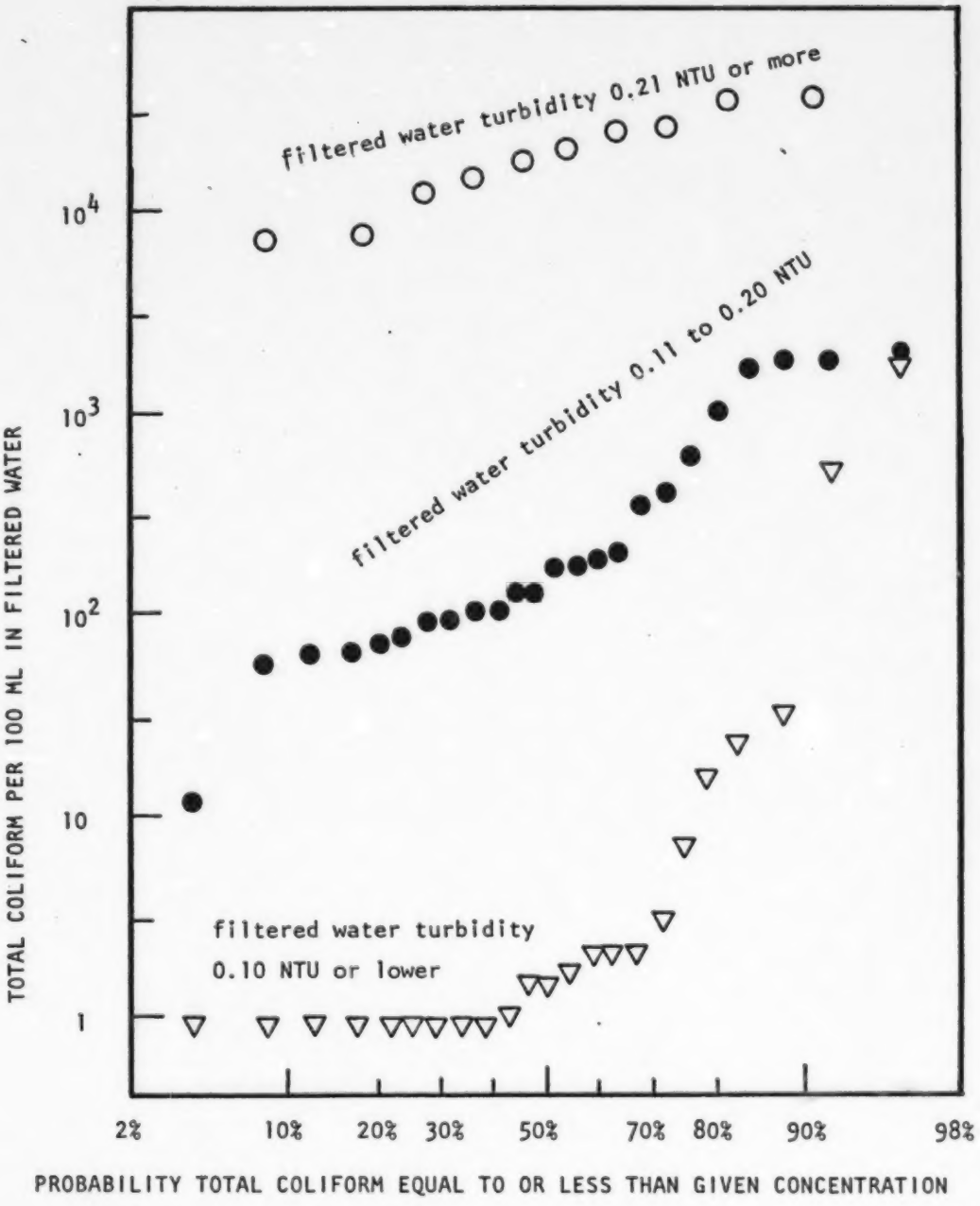

Figure 8. RELATIONSHIP OF TURBIDITY AND TOTAL COLIFORM CONCENTRATION IN FILTERED WATER (KLEBSIELLA SPIKING STUDIES)

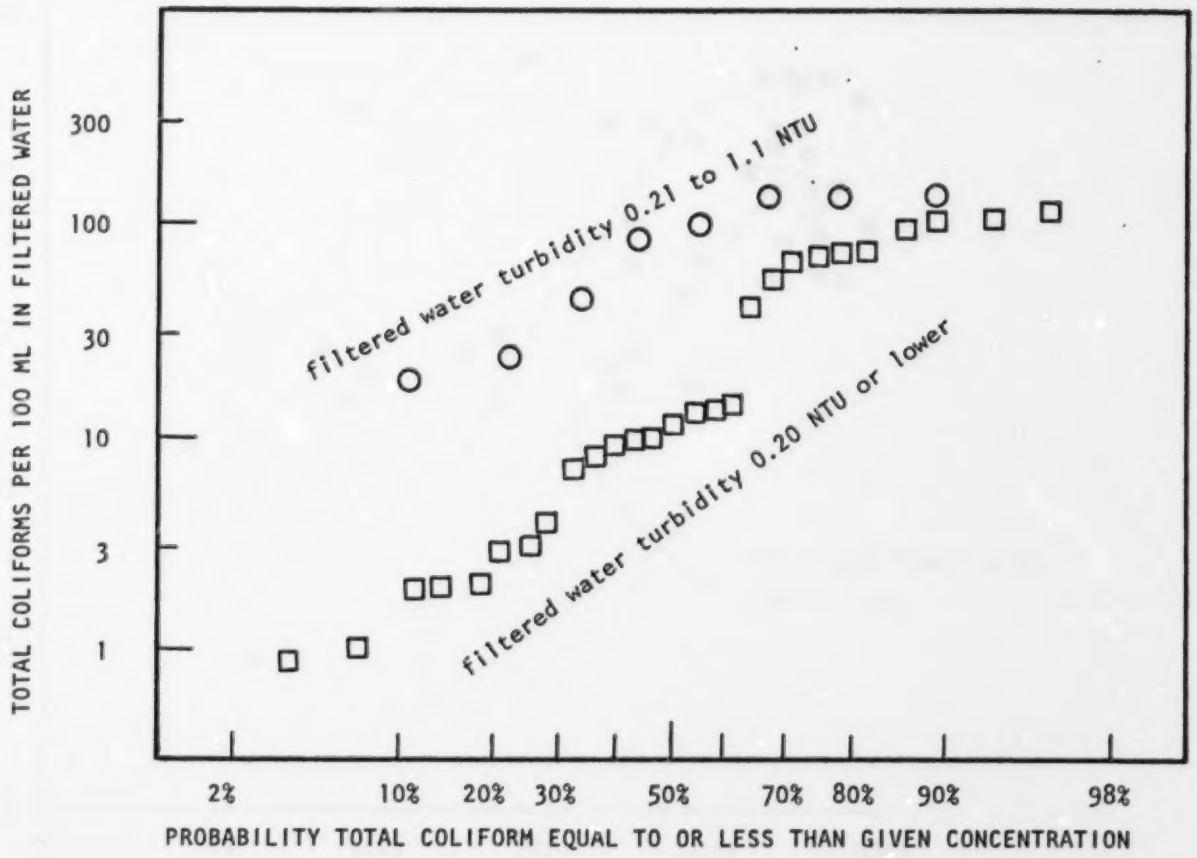

Figure 9. RELATIONSHIP OF TURBIDITY AND TOTAL COLIFORM CONCENTRATION IN FILTERED WATER (SEWAGE SPIKING STUDIES)

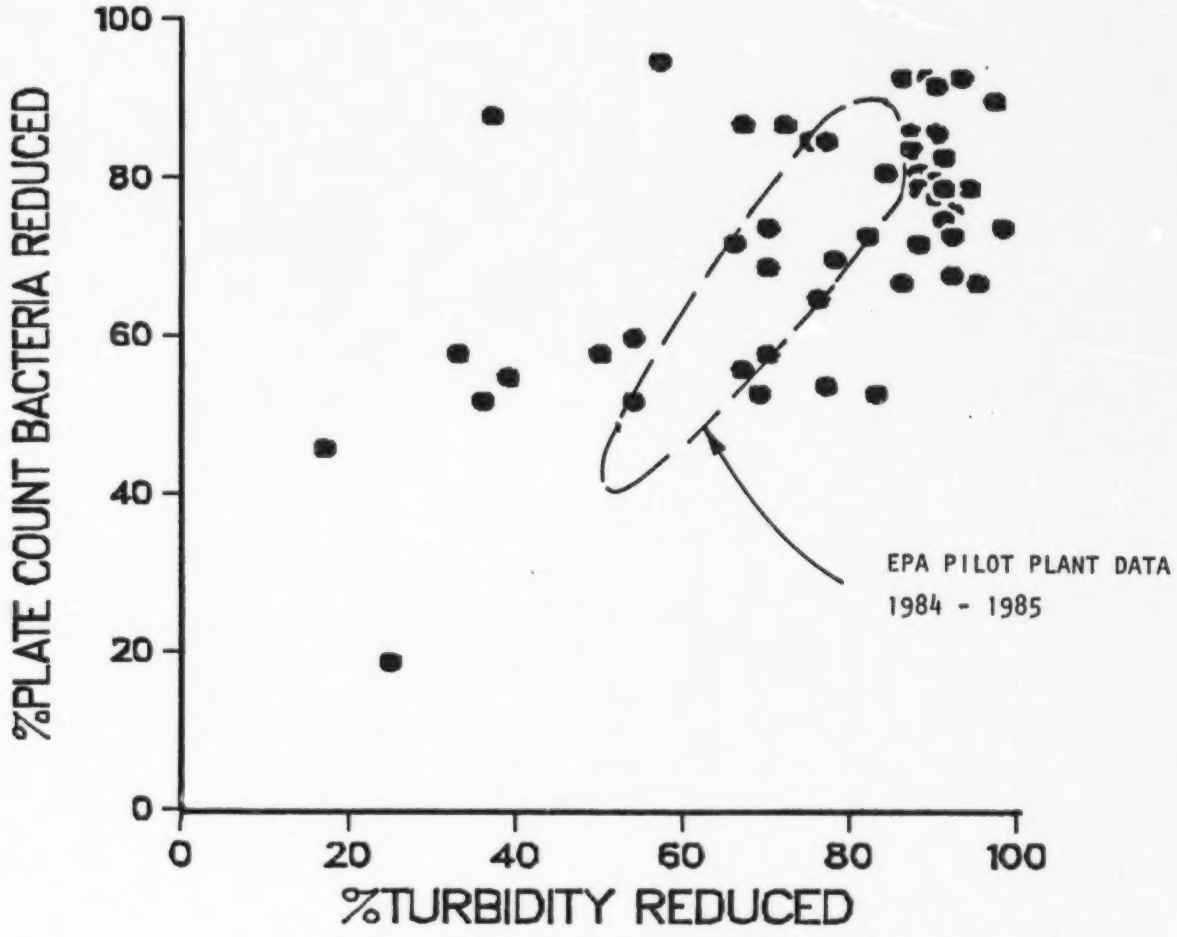

Figure 10.

COAGULATION-SEDIMENTATION RESULTS

CWW 1915-1916